NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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DYNAMOMETER-STAND INVESTIGATION OF A GROUP OF MUFFLERS

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SUMMARY

As part of a research program directed toward the reduction of airplane noises, an experimental investigation has been made of a series of exhaust mufflers installed on a typical six-cylinder light-airplane engine which was mounted on a ground dynamometer stand. The results show that engine and propeller noise are about equal for this installation; therefore, both engine-exhaust and propeller noises must be reduced to obtain a sizable reduction in over-all noise. Because most of the sound energy in the exhaust is found to be concentrated at low frequencies, methods applicable only to high-frequency sound are of little value in reducing the over-all sound-pressure level. The loudest single component of engine-exhaust noise is at the fundamental firing frequency of the engine. The types of present-day commercial airplane mufflers investigated are found to produce very little reduction in the over-all sound-pressure level. From the results of this exploratory investigation, several conclusions are drawn regarding the details of muffler design. For instance, the tail-pipe length is important, but the cross-sectional shape of the muffler (oval or circular) has no measurable effect on the muffler characteristics if the cross-sectional area and all other dimensions are constant.

INTRODUCTION

As part of a general research program directed toward the reduction of airplane noises, a theoretical and experimental investigation of the methods of muffler design is being conducted at the Langley full-scale tunnel. In order to obtain a sizable reduction in over-all noise, the reduction of both engine-exhaust and propeller noises is necessary. Consequently, because of the generally noisy propellers, relatively little attention has been given to airplane-engine-exhaust muffling in the past. Increasing interest in airplane quieting has made desirable an attack on both of these noise sources. The present investigation was undertaken in order to find a muffler which, in conjunction with a relatively quiet propeller, would substantially reduce the noise of a light airplane.

In the course of this muffler investigation a large number of exhaust mufflers were installed on a typical six-cylinder light-airplane engine. The tests were conducted with the engine mounted with the propeller removed in a ground dynamometer stand. Over-all noise levels

and noise spectrums were determined over a range of engine speed on the basic engine and on the engine with various muffler configurations attached. The results of ground tests of a low-frequency-pass multiple-resonant-chamber muffler are given in reference 1. This muffler was installed and flown on a light airplane in conjunction with a relatively quiet five-blade propeller for a demonstration of a "quiet" airplane (reference 2). Further experimental results of the muffler investigation are given in this paper in order to convey an idea of the relative performance of a large number of muffler configurations. The merits of a muffler must be based on physical size, weight, back pressure, and the annoyance of the exhaust noise. The annoyance depends upon the intensity and frequency of the noise and upon the particular person listening. At the present time no way exists to evaluate accurately the annoyance from objective measurements. In the present paper, therefore, muffler acoustic performance is given in terms of both the measured over-all sound-pressure levels and the frequency distribution of the sound.

MUFFLERS

The group of mufflers tested was composed of standard commercial mufflers, a special muffler designed for this project by a muffler manufacturer, a muffler constructed from a drawing shown in reference 3, and mufflers designed at the Langley Laboratory. The commercial mufflers were constructed of stainless steel. The mufflers built at the Langley Laboratory were constructed of mild steel tubing and sheet, since they were not intended for actual flight use.

Sketches of these mufflers, all drawn to the same scale, are included in table II. Unless otherwise specified, the flow is from left to right. Three-dimensional sketches showing internal details of several of these mufflers are given in figure 1 and photographs of several of the other mufflers are shown in figure 2.

APPARATUS AND TECHNIQUES

The test engine is a direct-drive, four-stroke, opposed six-cylinder engine of 435-cubic-inch displacement rated at 185 horsepower at 2550 rpm at sea level. This engine develops about 200 horsepower at 2790 rpm. The engine is equipped with two exhaust manifolds, one on each side of the engine as shown in figure 3. In order to install the mufflers the exit cones with the longitudinal slits at the ends of the exhaust pipes were removed, as shown in figure 4.

A photograph of the dynamometer setup is presented as figure 5. On the right-hand side of the photograph may be seen the engine and cowling which were taken as a unit from a military liaison airplane. Inasmuch as the propeller was removed for this investigation, the power from the engine was absorbed by means of an electric induction motor run as a generator with the power being fed into a variable-frequency alternator, which was utilized to absorb the output of the induction motor, feeding it into the the supply line, and to supply exciting current to the motor. The motor is rated at 266 horsepower at 3500 rpm and has power-speed characteristics similar to those of the engine at full-throttle operation. Cooling air for the cylinders and for the oil cooler was supplied by means of a blower installed within a duct that guided the flow to the engine and oil-cooler cooling-air inlets. A frequency analysis of the sound of the blower showed that the sound-pressure levels were sufficiently low and the frequencies sufficiently high to cause no interference with the engine sound measurements.

Standard instruments from the airplane were used to check engine operation except that engine speeds were determined with a combination of magnetic-drag aircraft tachometer generator and indicator. Thermocouples were installed in the spark-plug gaskets of the spark plugs nearest the exhaust ports to insure that the engine was not overheated during the tests. Engine back pressures were determined with a micromanometer connected to a static-pressure tap which was installed in the exhaust pipe from the left rear cylinder about 8 inches from the exhaust port.

A General Radio Company type 759-A sound-level meter was used to measure the over-all sound-pressure levels and a General Radio Company type 760-A sound analyzer to determine the noise spectrums. All noise levels were measured in decibels of sound intensity referred to the Acoustical Society of America standard base pressure level of 0.000204 dyne per square centimeter. The measurements of the over-all sound-pressure levels appear to be reliable and could be repeated. A few of the low analyzer readings, however, were lower than would be expected.

Noise-level measurements and spectrum analyses, with readings taken at multiples of one-half the firing frequency, were made at a point 50 feet from the ends of the original exhaust stacks on a line 135° to the right and rear of a line running forward in the plane of symmetry of the engine. The sound-level meter and the analyzer were placed on a board which rested directly on the ground. No corrections for ground reflections have been applied to the data presented in this paper. Over-all noise levels and spectrum analyses were measured at one, two, or all of the following speeds: 1650, 2000, and 2790 rpm. Engine back pressure was measured for many of the configurations.

RESULTS AND DISCUSSION

The results of this investigation of a large number of muffler configurations are presented in tabular form. Table I gives the results for tests with the propeller attached to the engine and table II presents the results for tests with the propeller removed. The over-all sound-pressure level and the frequency analysis of the sound are given for the configurations presented. Most of the engine-exhaust sound components are found at frequencies which are integral multiples of one-half the fundamental firing frequency of the engine. However, in a few cases, frequencies were found which did not bear this relationship to the fundamental. For these cases, and also for those cases in which sounds are found at frequencies above the seventh harmonic of the firing frequency, extra columns have been provided in table II, headed "Other sounds." The frequency and decibel level of two of these components are given in this column. Where more were found, the two loudest components are presented in the table. Back pressures are listed as low, medium, or high. At 2000 rpm back pressures below 0.8 psi are considered low, those from 0.8 psi to 1.2 psi are medium, and those above 1.2 psi are high. At 2790 rpm the medium-pressure range runs from 1.9 psi to 2.5 psi. In the few cases where back pressure is medium at one speed and high at another it is listed as medium. These back-pressure classifications have been arbitrarily chosen. The measurements indicated that the horsepower losses due to back pressure are small for the range of back pressure found in this investigation.

Table II may be consulted for detailed information on a particular muffler. The following discussion is intended to cover only general results of this investigation and is based on satisfactory muffler performance at engine speeds between 1650 and 2790 rpm. Engine speeds below cruising will be encountered in practice only at low engine power in taxying and for very short periods when opening the throttle for a take-off and throttling back for a glide; therefore, good attenuation characteristics may not be necessary below cruising speed. A muffler designed to operate only from cruising speed to maximum speed could probably be somewhat smaller than a muffler designed for the wide range of engine speed used in these tests.

Base Conditions

The frequency analysis of the first configuration listed in table I, consisting of the original engine with the propeller operating at 2000 rpm, full throttle, shows an over-all sound-pressure level of 98 decibels. The loudest component of the propeller noise is found at the fundamental frequency of the propeller (66.5 cps) with a level of 92 decibels, and the loudest component of the engine noise is found at the fundamental firing frequency of the engine (100 cps) with a level of 97 decibels. The over-all sound-pressure level of the propeller alone

must be at least 92 decibels; therefore, the maximum possible sound reduction by muffling alone is evidently no more than 6 decibels (from 98 db to 92 db) at this engine speed. At take-off speed (2550 rpm) the over-all sound-pressure level of the conventional airplane at 300 feet is 87.5 decibels (reference 2). When corrected to 50 feet, the distance at which the ground measurements were made, this sound level increases to 102.5 decibels. (Corrected flight data are used here because the top speed of the engine and propeller combination in the ground test stand is below 2550 rpm.) At the same engine speed the sound-pressure level of the conventional engine installation with the propeller removed, however, is 97.5 decibels (reference 1). Consequently, at some engine speed between 2000 and 2550 rpm the propeller and engine noises must be of equal intensity. For airplanes of this type, therefore, both propeller and engine noise must be reduced to achieve a significant reduction in over-all noise. In addition, because most of the exhaust sound energy is concentrated at low frequencies, sound-reduction methods applicable only to high-frequency sound are of little value in reducing the over-all sound-pressure level.

Several modifications not involving mufflers were made to the original exhaust system. When the two exhaust pipes were joined by a wye and exhausted through a common pipe (configuration 4, table II), a noticeable noise reduction was observed at the lower speeds. The data for this configuration with power off (engine switch off and throttle closed, engine being driven by the electric motor) give an indication of the lowest sound-pressure levels which can be obtained by exhaust muffling without also taking steps to silence the other engine noises. The wye is shown in use, with a typical muffler attached, in figure 6. The addition of a 90° elbow pointed upward (configuration 6, table II) resulted in a quite sizable noise reduction at all engine speeds. This simple upturned elbow proved more effective in reducing the over-all noise level than many of the small mufflers. The reason for this result is not clear, however, because theoretical considerations indicate that sound waves in this frequency range would have no strong directional properties after issuing from a $2\frac{3}{4}$-inch unflanged pipe. This fact is verified by radial surveys made in the plane of a straight horizontal exhaust pipe (fig. 7) which show that the variation of sound-pressure level with angular position is not large enough to account for the sound-level reduction obtained with this upturned elbow. The back pressure due to the bend and the sound reflections from the bend may possibly account for the observed sound reduction.

Commercial Mufflers

The mufflers discussed in this section were not designed for the particular engine which was used in this investigation. The airplane mufflers were, however, designed for other six-cylinder engines in the same general horsepower and speed range as the test engine; therefore, the results should be at least indicative of the performance to be

expected from these muffler types. The automobile muffler, on the other hand, was designed for an eight-cylinder engine of lower horsepower and higher speed than the test engine. Because of these fundamental differences, the results cannot be considered representative of the performance that this muffler would give when used with the automobile engine for which it was designed.

Airplane mufflers.- The commercial airplane mufflers produce very little reduction in the over-all sound-pressure level. These mufflers, however, are designed for and used on present-day light airplanes where, as has already been pointed out, the propeller noise is so high that no large reduction in exhaust noise is practical. These mufflers are shown in figure 2(a).

Automobile mufflers.- Most automobile mufflers contain internal baffles which force the exhaust-gas flow to reverse direction two or more times in passing through the mufflers. This type of muffler is unacceptable to airplane-engine manufacturers because of the high back pressures resulting from the flow reversals. Some automobile mufflers, however, are of the "straight-through" type, in which the stream of exhaust gas flows unobstructed through the muffler, and lower back pressure results. With an automobile muffler of the straight-through type (configuration 11, table II and fig. 1) attached to each of the two engine exhaust pipes many of the higher harmonics are reduced to below 60 decibels. The over-all level, however, which is 92 decibels at 2000 rpm, is only slightly lower than the level for the airplane mufflers because the fundamental note remains strong. A wye was attached to connect the original exhaust pipes and one of the automobile mufflers of configuration 11 was attached to the outlet of the wye. The results of this test (configuration 12, table II) show that this configuration produces a very marked reduction in the intensity of the fundamental note and reduces the over-all sound level from 92 decibels with two mufflers to 85 decibels with one muffler at 2000 rpm. For this installation one muffler attached to a collector pipe has proved to be more effective than two identical mufflers attached to separate cylinder banks. This result may be due, at least in part, to increased back pressure. The single automobile muffler, which was designed for a smaller engine, is unable to handle the large volume of exhaust-gas flow from the airplane engine without excessive back pressure; therefore this particular arrangement is considered unsatisfactory for the engine used in this investigation.

Special Commercial Muffler

A special muffler was designed for this engine by a commercial firm. This straight-through type of muffler, a three-dimensional cutaway view of which is shown as muffler 13 in figure 1, accomplished a large reduction in over-all noise. Unfortunately, however, the back pressure is high. This muffler (muffler 13, table II) had an over-all sound-pressure

level of 83.5 decibels at 2000 rpm, with high back pressure. Another, and supposedly identical, muffler (muffler 14, table II) had a slightly lower back pressure and a higher sound level (88.5 db at 2000 rpm) than the first. Mufflers 13 and 14 and also muffler 12, discussed in the preceding section, have excessive back pressure even though they are straight-through types. The back pressure can be reduced by increasing the diameter of the central tube. The equations presented in reference 1 show, however, that if the central-tube diameter is increased to lower the back pressure, the outside diameter of the muffler must be increased in approximately the same proportion to avoid loss in attenuation. Consequently, the lower the required back pressure, the larger the muffler must be.

Burgess-Farnborough Silencer, Type K

A Burgess-Farnborough silencer, type K (muffler 16 of table II and fig. 1) was designed to silence one of two banks of cylinders on a 450-horsepower engine (reference 3). When installed on the engine used in this investigation it reduced the sound-pressure level to 83 decibels at 2000 rpm. This muffler is the most effective one so far discussed, but it is about 8 feet long. Because of the generous proportions of this muffler the internal velocities are low. The highest internal dynamic pressure is about one-fourth that in the $2\frac{3}{4}$-inch exhaust pipe. The flow losses in the muffler, consequently, are small and the back pressure is quite low in spite of the baffle at the rear of the second chamber. When the rear half of this muffler was used alone (muffler 17, table II) the sound level increased from 83 to 92 decibels at 2000 rpm. The large chamber at the front of the muffler therefore apparently produces most of the silencing at the lower frequencies. At the lowest engine speed, 1650 rpm, where the exhaust frequencies are low, more noise passes through the muffler than at the higher engine speeds.

NACA-Designed Mufflers

Inasmuch as none of the mufflers discussed so far seemed wholly satisfactory for the test engine, an attempt was made to design a more suitable muffler. In the course of this investigation a large number of configurations were tried in order to study the basic characteristics of resonant-chamber and expansion-chamber mufflers.

Resonant-chamber types.- The development of muffler 19 (table II and fig. 1) proved especially informative because of the significant muffler properties demonstrated. This muffler was originally expected to work largely through the absorption of sound-pressure waves by the steel-wool packing. The results show that it reduces the sound-pressure level to 89 decibels at 2000 rpm and that its effectiveness is least at the lower frequencies. Closing the exit from the outer steel-wool chamber (muffler 20, table II) sharply increases the low-frequency

effectiveness of the muffler and reduces the sound-pressure level to 86 decibels at 2000 rpm; therefore, the results indicate that the muffler acts more as a volume resonator than as a sound-energy absorber. The results obtained with the steel wool removed (muffler 21, table II) strengthen this view, because the low-frequency effectiveness is again increased. No increase in the over-all effectiveness occurred, however, because the second harmonic intensity increased. Various lengths of tail pipe were attached to this muffler (configurations 22 to 29, table II). The results show the large effect which the tail pipe may exert on the exhaust-system noise characteristics. For example, figure 8 shows that at 2000 rpm the sound-pressure levels of the first three harmonics vary continuously as the tail-pipe length is varied. At the same time the over-all level varies from 83 to 86 decibels. In addition, certain "other sounds" of various frequencies become more or less prominent as the tail-pipe length is altered. These other sounds all occur approximately at multiples of $16\frac{2}{3}$ cycles per second, which is the firing frequency of one cylinder of the engine at 2000 rpm. Although the tail pipe can produce considerable attenuation at certain frequencies, it can also reduce the muffler effectiveness at other frequencies, so the choice of tail-pipe length is very important in the design of a muffler installation. Data from configuration 21 are not plotted in figure 8 because of changes in the length of the inlet wye between the tests of muffler 21 and the tests of configurations 22 to 28.

Muffler 30 was designed, by using the formulas of reference 1, to give good attenuation over the complete frequency band (up to 1000 cps) which would be encountered at 2000 rpm. Asbestos packing was placed around the outside of the muffler to reduce the noise radiation from the muffler shell. (See fig. 1.) Although the muffler is quite effective it does not meet the original expectations, particularly at the second harmonic. In the design of this muffler the connecting holes in the large chambers were made small in an attempt to hold the chamber size required for the chosen value of cut-off frequency to a minimum. The area of the connecting orifices, however, may have been so small as to impair the silencing characteristics. Additional connecting orifices were drilled and the results of the tests (muffler 31, table II) support this view, because the second harmonic is reduced 28 decibels by this change. The low-frequency characteristics are slightly impaired, but nevertheless the over-all sound-pressure level of 82 decibels at 2000 rpm is the lowest attained by any muffler thus far discussed. The reduction of the exhaust-pipe diameter to 2 inches in the design of this muffler results in excessive back pressure. The over-all sound level of muffler 31 at 2000 rpm is not changed by removing the asbestos jacket (muffler 32, table II), nor is it changed by removing the high-frequency chambers (muffler 33, table II). Removal of one of the three large low-frequency chambers results in a 4-decibel noise increase (muffler 34, table II). Removal of all four medium-frequency chambers results in only a 1.5-decibel further noise increase (mufflers 35 and 36, table II). Elimination of one of the two low-frequency chambers

results in an additional sharp noise increase of 7 decibels (muffler 37, table II). These characteristics indicate that the noise reduction is principally due to the low-frequency chambers, so for this engine a small number of large low-frequency chambers would be much more effective than a large number of small high-frequency chambers. This result agrees with the design equations of reference 1, which state that the low-frequency cut-off of a muffler of this type is inversely proportional to the square root of the chamber volume.

Several arrangements utilizing two resonant chambers were investigated and some had excellent muffling capabilities. Included in this group was the muffler used in the demonstration of light-airplane noise reduction (muffler 43, table II, fig. 1, and reference 1). In the process of this investigation one of the mufflers was received and tested with the central baffle spot-welded at only four points on the circumference. The baffle was later seam-welded to eliminate any leakage between the two chambers and the muffler was retested. The sound-pressure level for the 1650-rpm condition is reduced more than 10 decibels by this means, this reduction indicating that there should be no leakage between the chambers. The back pressures of these straight-through mufflers with a $2\frac{3}{4}$-inch-diameter central tube are, in general, lower than those for the original engine installation at 1650 rpm and 2000 rpm but are higher at 2790 rpm.

The muffler attenuation curves of reference 1 show that in order to obtain sufficient noise reduction the cut-off frequency must be chosen somewhat below the lowest frequency for which attenuation is desired. An allowance must also be made in the design of a muffler for the accuracy with which the exhaust-gas temperature, and hence the speed of sound, is known and for the fact that this temperature is not constant. The effect of choosing the design cut-off frequency too close to the engine fundamental frequency, at which high attenuation is required, was demonstrated by the tests of muffler 49, which was designed for a low-frequency cut-off about 7 percent lower than the fundamental frequency at 2790 rpm. The performance of this muffler was poor, inasmuch as the sound-pressure level of the engine fundamental was 97 decibels at 2790 rpm with this muffler, which is only 4 decibels below that with the wye alone (configuration 4, table II). Note that at 2000 rpm the fundamental, which is lower than the design cut-off frequency, is not attenuated by muffler 49.

An attempt was made to shape a resonant-chamber muffler to have the largest volume possible in the available space within the engine cowling (fig. 2(b)). This particular muffler (muffler 57, table II) was of little value as a noise reducer because the flat sides vibrated with the exhaust pulses and radiated sound. This muffler was modified by connecting the resonant chambers (fig. 2(c) and muffler 58, table II) with the hope that such an alteration might have a beneficial effect similar to that obtained by joining the two exhaust pipes ahead of the

muffler. In addition, stiffeners were added to the flat sides of the muffler. The vibration of the sides was so severe, however, that the stiffeners broke loose during the test. Mufflers of this type, with large flat sides, were therefore discarded as impractical.

Expansion-chamber types.- Several expansion-chamber types of mufflers were investigated and some were very effective, although in general the back pressures were higher than for the straight-through type of mufflers due to energy losses in the expansion process. Not only with these expansion-chamber but also with the resonant-chamber types, the use of an oval cross section instead of a circular cross section for the outside shell has no measurable effect on the over-all sound-pressure level, provided the cross-sectional area is the same in both cases. This result is a check with the theory, which indicates that if only plane pressure waves need be considered the attenuation will not be a function of the cross-sectional shape of an expansion chamber. An oval shape is sometimes preferred because of the particular space requirements in a specific installation. Tests of a 3-inch by 12-inch by 24-inch oval muffler with two different tail-pipe lengths (configurations 64 and 65, table II) show how the effectiveness of such a muffler can be increased by the proper choice of tail-pipe length. The over-all sound-pressure level is reduced from 91.6 to 87 decibels at 2000 rpm by making the tail pipe long enough to bring the resonant frequency of the muffler and tail-pipe combination, considered as a Helmholtz resonator, well below the lowest frequency present in the exhaust. The longer tail pipe reduces the intensity of the fundamental frequency component at 2000 rpm from 91 to 80 decibels.

Even with the proper choice of tail-pipe configuration, the over-all sound-pressure level is 5.5 to 6.5 decibels higher for muffler 65 than for muffler 62, which has a chamber volume about four times higher than that of muffler 65. Thus, for expansion-chamber mufflers, as was also discovered in the case of resonant-chamber mufflers, large chamber volumes are required for the reduction of low-frequency noise.

Combinations.- A muffler consisting of a single expansion chamber and a single resonant chamber in combination as a unit (muffler 67, table II) produced excellent attenuation with a reasonable value of back pressure, yet it was only 30 inches long, which is considerably shorter than other mufflers of similar performance. This result shows that it is possible to build a much smaller muffler than the one used in the flight demonstration with little sacrifice in performance. Inasmuch as no concerted effort was made to obtain a muffler of minimum size, it is quite possible that a muffler of equal performance even smaller than muffler 67 could be designed for the same speed range. Another combination consisting of two of the best mufflers (mufflers 62 and 45) placed in series was tested (fig. 2(e) and muffler 68, table II). The resultant sound-pressure levels are regarded as the lowest which can be obtained with this engine by means of exhaust muffling alone. For example, the over-all sound-pressure level at 2000 rpm is reduced to 79.5 decibels. The remaining sound is believed to consist mostly of engine air intake and clatter noises.

CONCLUSIONS

An experimental investigation has been made of the noise of a typical six-cylinder light-airplane engine and propeller combination and of the exhaust noise of the same engine without the propeller with a series of 68 muffler and tail-pipe configurations. The following conclusions have been drawn from the results of this investigation:

1. Since engine and propeller noise are about equal for this power-plant installation, both engine-exhaust and propeller noises must be reduced to obtain a sizable reduction in the over-all sound-pressure level.

2. Most of the exhaust sound energy is concentrated at low frequencies; therefore, sound-reduction methods applicable only to high-frequency sound are of little value in reducing the over-all sound-pressure level. The loudest component of engine-exhaust noise is at the fundamental firing frequency of the engine.

3. The types of present-day commercial airplane mufflers investigated produced very little reduction in the over-all sound-pressure level.

4. From the results of this exploratory investigation the following conclusions regarding the details of muffler design for light aircraft may be drawn:

a. Both resonant-chamber and expansion-chamber mufflers require large chamber volumes to reduce low-frequency noise.

b. If the low-frequency cut-off point is chosen too close to the fundamental firing frequency of the engine the sound-pressure reduction will be low.

c. Baffles between muffler chambers must be well sealed to avoid leakage or the muffler characteristics will be altered.

d. Mufflers of a given cross-sectional area of either circular or oval cross section, with all other dimensions the same, appear to give equal results.

e. The lower the required back pressure, the larger the muffler must be.

f. The straight-through or resonant-chamber mufflers have lower back pressure, in general, than the expansion-chamber mufflers.

g. The tail-pipe configuration chosen may have a large effect on the exhaust-system characteristics.

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National Advisory Committee for Aeronautics
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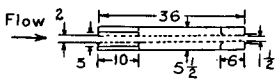
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TABLE I.- ENGINE AND PROPELLER NOISE

	Configuration	Engine speed (rpm)	Engine fundamental frequency, F (cps)	Propeller fundamental frequency, F' (cps)	Sound-pressure level (db)								
					Over-all	F'	F	2F'	1.5F	2F = 3F'	2.5F	3F	4F = 6F'
1	Original engine installation (See fig. 3)	2000	100	66.5	98	92	97	80	76	80	(a)	67	(a)
2	Exhaust manifold removed	2000	100	66.5	100	90	97	82	78	87	75	68	67

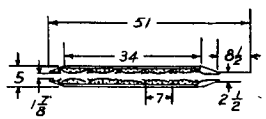
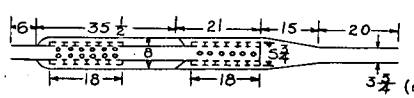
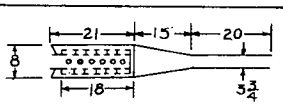
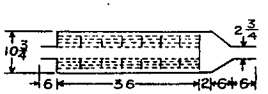
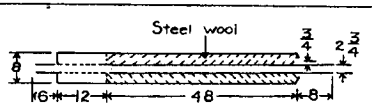
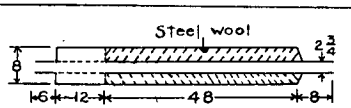
[a]The sound-pressure level was below the range of the analyzer.

TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED

	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)															Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
1	Original exhaust manifold with tapered exit cones (see fig. 3)	1650 2000 2790	82.5 100.0 139.5	97.0 98.0 97.5	58 68 77	97 98 97	81 72 87	81 82 81	70 79 75	70 68 72	65 67 75	63 65 72	63 65 67	58 63 65	58 62 63	57 60 (b)	55 60 (b)	57 57 (b)	---- ---- ----	-- -- --	---- ---- ----	-- -- --	Medium
2	Original exhaust manifold with exit cones removed (see fig. 4)	1650 2000 2790	82.5 100.0 139.5	97.5 99.0 100.0	63 65 75	97 98 98	80 75 90	86 85 88	70 75 87	70 78 73	68 72 70	60 63 67	57 63 66	55 63 65	55 60 65	55 58 (b)	55 57 (b)	55 57 (b)	---- ---- ----	-- -- --	---- ---- ----	-- -- --	Low
3	Exhaust manifold removed	1650 2000 2790	82.5 100.0 139.5	98.0 98.5 102.0	65 67 65	98 97 99	90 86 80	82 88 80	70 85 75	72 73 72	77 75 70	72 78 71	72 71 72	75 72 73	65 71 73	63 75 70	64 71 (b)	65 70 (b)	619 750 ----	63 70 --	---- ---- ----	-- -- --	------
4	Open wye	1650 [c]1650 2000 2790 [c]2790	82.5 82.5 100.0 139.5 139.5	91.5 78.0 95.0 102.0 87.5	50 61 55 75 62	80 67 91 101 87	63 67 67 80 68	89 74 92 96 78	67 59 67 80 62	75 60 70 84 70	71 62 65 86 55	72 58 79 84 54	65 49 63 80 52	61 50 72 (b) (b)	65 52 62 (b) (b)	57 50 70 (b) (b)	55 54 57 (b) (b)	55 59 65 (b) (b)	260 190 ---- 375 230	77 66 -- 88 72	743 275 ---- 322 47	63 64 -- 84 71	Low
5	Open wye with 126-inch exhaust pipe	1650 2000 2790	82.5 100.0 139.5	93.0 94.5 104.5	60 (b) (b)	93 93 104	65 67 80	83 88 95	65 70 90	75 73 95	68 68 80	65 78 89	65 72 84	65 67 72	60 65 77	60 65 72	(b) 65 (b)	(b) 67 (b)	---- 750 330	-- 70 84	---- ---- 1230	-- -- 84	Medium
6	Open wye with 90° upturned elbow	1650 2000 2790	82.5 100.0 139.5	86.0 88.0 97.5	45 50 60	78 86 96	61 63 73	84 84 91	65 70 73	75 84 73	66 69 75	73 63 75	67 65 70	61 63 79	57 57 80	55 58 72	55 57 (b)	53 58 (b)	275 465 ----	72 70 --	750 800 ----	65 61 --	Medium
7	Two commercial airplane mufflers (see fig. 2(a))	2000	100.0	95.0	77	90	89	86	86	79	80	65	65	70	65	68	(b)	(b)	----	--	----	--	------
8	One commercial airplane muffler-heater and one muffler (see fig. 2(a))	1650 2000 2790	82.5 100.0 139.5	89.0 95.0 94.0	77 82 89	85 86 90	87 95 85	77 81 92	71 85 72	73 87 66	67 76 68	65 70 73	63 67 65	62 65 68	61 68 63	55 65 60	60 60 (b)	58 60 (b)	619 750 ----	55 62 --	---- ---- ----	-- -- --	Low
9	Two commercial airplane mufflers (see fig. 2(a))	1650 2000 2790	82.5 100.0 139.5	92.0 96.0 98.0	76 84 95	81 84 93	91 95 92	73 81 93	74 88 72	68 86 70	69 82 68	63 71 73	62 66 74	60 65 73	55 65 72	55 65 67	55 65 70	55 62 (b)	619 750 ----	55 66 --	---- 800 ----	-- 63 --	Low
10	Two commercial airplane muffler-heaters (see fig. 2(a))	1650 2000 2790	82.5 100.0 139.5	89.0 93.0 95.5	80 70 78	86 87 81	87 93 88	80 79 79	82 88 70	72 80 62	78 79 60	69 67 63	70 63 65	67 62 60	60 65 67	60 65 65	62 65 (b)	61 63 (b)	619 750 ----	62 65 --	---- 800 ----	-- 65 --	Low
11	 2 mufflers, one on each bank of cylinders (see fig. 1)	2000	100.0	92.0	78	91	84	(b)	81	(b)	67	(b)	(b)	70	(b)	(b)	(b)	(b)	----	--	----	--	Low
12	1 muffler, same as 11	2000	100.0	85.0	55	77	60	81	60	81	59	58	55	61	52	55	(b)	(b)	----	--	----	--	High

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.
[b] The sound-pressure level was below the range of the analyzer.
[c] Power off.

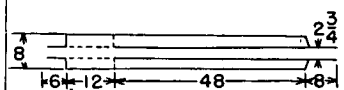
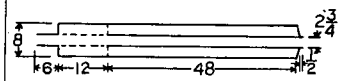
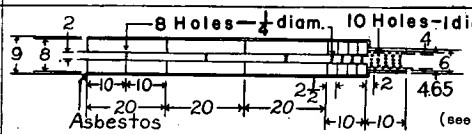
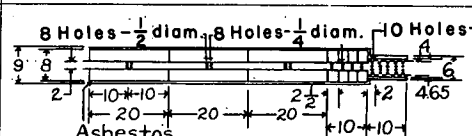
TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Continued

	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)														Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
13	 (see fig. 1)	1650 2000 2790	82.5 100.0 139.5	83.0 83.5 89.5	48 50 55	83 83 86	60 60 75	81 79 87	59 70 78	65 80 82	62 63 73	67 62 69	55 60 62	55 56 58	53 55 60	50 53 (b)	50 50 (b)	50 48 (b)	624 ---- ----	47 -- --	707 ---- ----	47 -- --	High
14	Same as 13	2000 2790	100.0 139.5	88.5 94.0	---- 57	---- 94	---- 70	---- 93	---- 73	---- 80	---- 70	---- 65	---- 57	---- 58	---- 58	---- (b)	---- (b)	---- (b)	---- ----	-- --	---- ----	-- --	High
15	13 reversed	1650 2000 2790	82.5 100.0 139.5	86.5 85.5 92.0	50 50 58	85 84 90	62 58 62	83 73 78	62 66 62	66 82 65	65 65 63	70 60 60	58 57 60	55 55 55	55 53 55	55 50 (b)	53 48 (b)	52 45 (b)	---- ---- ----	-- -- --	---- ---- ----	-- -- --	High
16	 (see fig. 1)	2000	100.0	83.0	55	81	50	71	60	70	55	65	55	50	53	50	(b)	(b)	435	62	----	--	Low
17		1650 2000 2790	82.5 100.0 139.5	96.0 92.0 92.5	66 63 ----	96 91 ----	76 65 ----	86 80 ----	70 68 ----	77 72 ----	76 72 ----	86 80 ----	75 81 ----	76 72 ----	70 63 ----	65 60 ----	(b) (b) ----	(b) (b) ----	---- ---- ----	-- -- --	---- ---- ----	-- -- --	Low
18	 (see fig. 1)	1650 2000 2790	82.5 100.0 139.5	96.0 94.0 100.5	---- (b) ----	---- 94 ----	---- (b) ----	---- 86 ----	---- 75 ----	---- 78 ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- ---- ----	-- -- --	---- ---- ----	-- -- --	Medium
19	 (see fig. 1)	2000	100.0	89.0	55	89	(b)	83	(b)	69	(b)	81	(b)	65	(b)	(b)	(b)	(b)	----	--	----	--	Medium
20		1650 2000	82.5 100.0	84.0 86.0	62 55	84 80	60 56	68 85	(b) 58	68 67	(b) 53	(b) 75	(b) 56	60 60	(b) 55	(b) 57	(b) (b)	(b) (b)	---- ----	-- --	---- ----	-- --	Medium

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.

[b] The sound-pressure level was below the range of the analyzer.

TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Continued

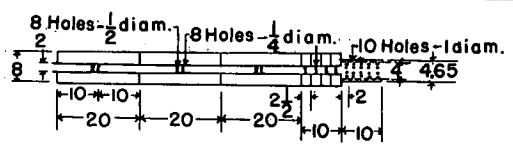
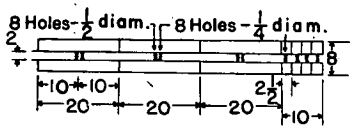
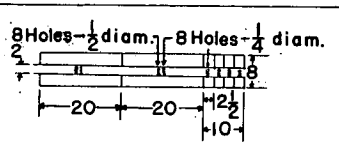
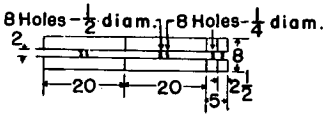
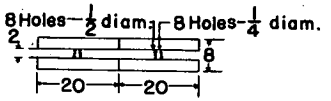
	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)															Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
21		2000	100.0	87.0	45	72	61	87	60	63	56	67	58	58	53	57	52	(b)	435	66	----	--	Medium
22		1650 2000	82.5 100.0	86.0 84.5	53 60	86 80	58 60	55 60	55 58	70 68	60 68	58 80	68 65	72 60	(b) 55	(b) 66	(b) (b)	(b) (b)	---- 330	-- 77	---- 265	-- 65	Medium
23	Same as 22 except 16 1/8-inch tail pipe	1650 2000	82.5 100.0	85.5 85.0	53 60	85 78	56 55	60 75	62 74	81 76	70 72	69 75	(b) 60	68 57	(b) 60	(b) 60	(b) (b)	(b) (b)	---- 330	-- 82	---- 750	-- 62	Medium
24	Same as 22 except 32 1/4-inch tail pipe	1650 2000	82.5 100.0	84.0 86.0	(b) 56	72 73	43 58	57 81	62 65	66 73	55 70	52 83	64 67	70 60	(b) 60	(b) 62	(b) (b)	(b) 60	---- ----	-- --	---- ----	-- --	Medium
25	Same as 22 except 50-inch tail pipe	2000	100.0	83.5	56	71	55	73	64	77	70	65	62	57	57	57	(b)	(b)	335	77	----	--	Medium
26	Same as 22 except 60-inch tail pipe	2000	100.0	83.0	55	73	55	72	66	76	69	77	63	58	61	58	(b)	(b)	267	77	----	--	Medium
27	Same as 22 except 70-inch tail pipe	2000	100.0	84.5	57	74	55	73	62	73	74	65	60	60	58	65	(b)	(b)	368	80	----	--	Medium
28	Same as 22 except 90 1/2-inch tail pipe	2000	100.0	85.5	57	82	57	76	63	79	72	81	65	60	57	70	(b)	66	330	72	----	--	Medium
29	Muffler 22 reversed with 32-inch tail pipe	2000	100.0	83.0	60	72	63	65	67	77	83	70	60	58	55	57	(b)	(b)	----	--	----	--	Medium
30	 (see fig. 1).	2000	100.0	86.0	56	75	62	86	60	73	69	67	61	58	55	55	(b)	60	33.3	60	----	--	High
31		1650 2000	82.5 100.0	82.0 82.0	(b) (b)	80 77	55 53	63 58	53 55	55 67	52 53	(b) (b)	(b) (b)	(b) (b)	(b) (b)	(b) (b)	(b) (b)	(b) (b)	---- ----	-- --	---- ----	-- --	High

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.

[b] The sound-pressure level was below the range of the analyzer.

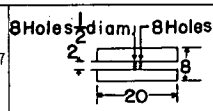
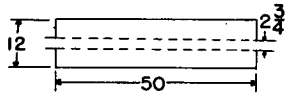
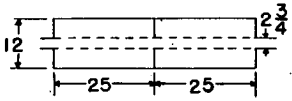
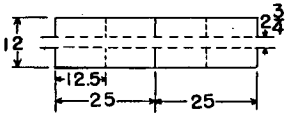
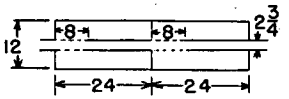
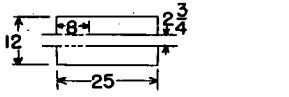
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TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Continued

	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)															Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
32		1650 2000 2790	82.5 100.0 139.5	79.5 82.0 88.0	---- 50 ----	---- 77 ----	---- 50 ----	---- 62 ----	---- 55 ----	---- 60 ----	---- 50 ----	---- 50 ----	---- 50 ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- ---- ----	-- -- --	---- ---- ----	-- -- --	High
33		1650 2000	82.5 100.0	79.0 82.0	---- (b)	---- 77	---- 50	---- 59	---- 50	---- 60	---- 50	---- 50	---- 50	---- (b)	---- (b)	---- (b)	---- (b)	---- (b)	---- ----	-- --	---- ----	-- --	High
34		2000	100.0	86.0	54	86	60	78	58	71	59	62	57	57	55	59	(b)	(b)	133	60	----	--	High
35		2000	100.0	87.0	57	87	64	76	64	68	64	73	62	64	59	59	59	57	365	67	800	57	High
36		2000	100.0	87.5	48	87	57	77	53	68	58	60	58	48	48	48	53	60	----	--	----	--	High

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.
[b] The sound-pressure level was below the range of the analyzer.

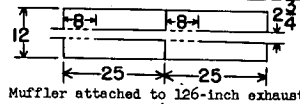
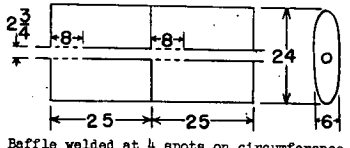
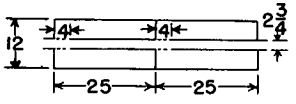
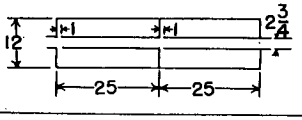
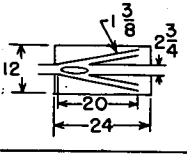
TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Continued

Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)														Other sounds				Back pressure
			Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
37 	2000	100.0	94.5	(b)	93	68	85	74	80	70	74	68	63	65	62	(b)	(b)	425	76	800	71	High
38 	1650 2000 2790	82.5 100.0 139.5	81.0 83.5 87.5	40 45 50	74 66 84	52 48 67	72 62 77	60 69 62	70 76 60	55 60 70	59 53 65	52 57 55	49 53 55	51 50 (b)	48 52 (b)	47 50 (b)	47 45 (b)	---- ---- ----	-- -- --	---- ---- ----	-- -- --	Medium
39 	1650 2000 2790	82.5 100.0 139.5	78.5 83.0 89.0	43 45 62	72 76 88	57 55 78	70 60 80	51 55 77	57 77 73	53 60 69	55 55 63	57 60 58	51 55 55	55 51 58	50 52 56	45 (b) (b)	50 (b) (b)	118 ---- ----	65 -- --	55 ---- ----	57 -- --	Medium
40  (see fig. 1)	1650 2000 2790	82.5 100.0 139.5	79.5 81.5 87.0	44 (b) 62	78 66 85	69 (b) 62	49 (b) 82	47 50 65	52 72 67	47 53 69	52 57 60	55 57 58	53 52 61	51 (b) 63	51 (b) 65	48 (b) 65	48 (b) 70	---- 128 ----	-- 56 --	---- ---- ----	-- -- --	Medium
41 	1650 2000 2790	82.5 100.0 139.5	83.0 83.0 88.0	48 50 60	82 70 85	50 48 60	50 50 75	50 55 82	50 74 79	47 57 78	48 57 69	50 67 60	55 62 58	60 58 (b)	60 58 (b)	50 53 (b)	50 50 (b)	---- ---- 390	-- -- 69	---- ---- ----	-- -- --	Medium
42 	1650 2000 2790	82.5 100.0 139.5	88.0 88.0 99.0	52 55 63	86 87 97	66 66 77	85 84 94	67 74 81	82 74 86	65 66 79	70 63 71	63 68 69	58 68 68	62 60 70	58 58 67	55 58 (b)	52 58 (b)	618 750 ----	52 57 --	660 ---- ----	52 -- --	Medium

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.
[b] The sound-pressure level was below the range of the analyzer.

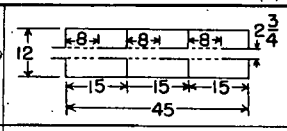
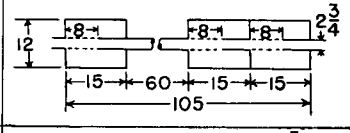
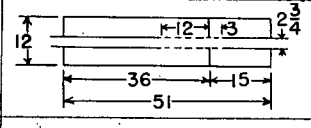
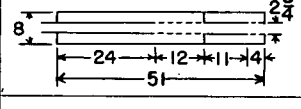
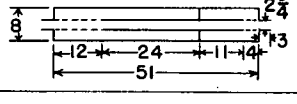
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TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Continued

	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)															Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
43	 Muffler attached to 126-inch exhaust pipe and terminated with upturned elbow (see fig. 1)	1650	82.5	76.0	40	76	52	52	46	50	47	45	45	52	50	45	40	40	----	--	----	--	Medium
		2000	100.0	83.0	50	83	50	50	(b)	52	50	50	50	(b)	(b)	(b)	(b)	(b)	----	--	----	--	
		2790	139.5	82.5	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	--	----	--	
44	 Baffle welded at 4 spots on circumference	1650	82.5	91.0	(b)	45	83	62	52	52	45	53	53	50	45	45	(b)	(b)	----	--	----	--	Medium
		2000	100.0	84.5	45	66	47	55	60	81	63	63	70	67	60	55	(b)	(b)	----	--	----	--	
		2790	139.5	91.0	(b)	88	65	70	72	86	84	65	64	60	(b)	(b)	(b)	(b)	----	--	----	--	
45	Baffle seam welded; otherwise same as 44 (see fig. 2(e))	1650	82.5	80.5	(b)	73	50	51	(b)	50	52	50	51	53	59	50	50	(b)	----	--	----	--	Medium
		2000	100.0	83.0	50	65	50	50	59	83	66	66	63	62	(b)	(b)	(b)	(b)	----	--	----	--	
		2790	139.5	87.0	58	84	58	60	65	84	72	63	66	66	(b)	(b)	(b)	(b)	450	81	800	70	
46		1650	82.5	77.0	35	68	65	48	55	57	50	56	64	70	65	59	53	52	240	63	750	55	Low
		2000	100.0	81.5	(b)	67	45	50	54	69	58	69	59	53	50	48	49	51	420	74	115	60	
		2790	139.5	86.0	54	84	58	73	63	78	71	60	61	67	69	67	(b)	(b)	750	77	380	69	
47		1650	82.5	81.5	(b)	71	45	63	45	45	53	62	59	53	50	45	52	51	360	61	690	55	Low
		2000	100.0	82.5	45	59	45	62	48	60	60	62	55	53	55	53	60	57	370	67	750	60	
		2790	139.5	93.5	55	90	60	79	68	72	65	69	75	72	79	65	(b)	(b)	375	81	330	71	
48	 (see fig. 1)	1650	82.5	84.0	(b)	75	63	81	67	70	71	73	63	63	60	57	56	58	742	62	783	65	Low
		2000	100.0	86.0	45	78	62	84	72	82	69	71	72	62	63	60	58	58	390	73	800	67	
		2790	139.5	101.5	64	96	79	95	86	95	85	84	73	72	77	76	77	70	1250	72	1400	73	

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.
[b] The sound-pressure level was below the range of the analyzer.

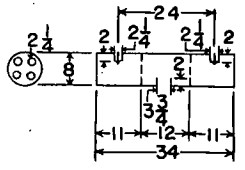
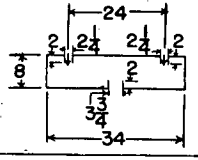
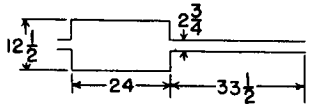
TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Continued

	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)															Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
49		2000 2790	100.0 139.5	92.0 97.0	60 65	92 97	62 75	72 87	(b) 65	82 81	(b) 60	(b) 65	(b) (b)	(b) 70	(b) (b)	(b) (b)	(b) (b)	(b) (b)	---- ----	-- --	---- ----	-- --	Medium
50		1650 2000 2790	82.5 100.0 139.5	79.0 81.5 87.5	45 45 53	77 68 87	58 54 64	73 69 83	50 55 64	54 70 62	51 52 57	53 47 63	50 45 62	50 50 68	47 50 72	50 53 70	51 52 (b)	50 50 (b)	619 750 ----	50 50 --	55 ---- ----	55 -- --	Medium
51		1650 2000 2790	82.5 100.0 139.5	93.0 88.0 99.0	---- 64 ----	---- 87 ----	---- 72 ----	---- 81 ----	---- 57 ----	---- 57 ----	---- 61 ----	---- 65 ----	---- 57 ----	---- 59 ----	---- 52 ----	---- 57 ----	---- 57 ----	---- 59 ----	---- 135 ----	-- 76 --	---- 370 ----	-- 63 --	Low
52	Muffler 51 reversed	2000	100.0	87.5	46	87	54	74	61	81	64	70	59	54	51	59	61	62	135	68	370	68	Low
53		2000	100.0	92.5	(b)	92	(b)	72	(b)	60	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)	----	--	----	--	Low
54	Muffler 53 reversed	2000	100.0	89.5	(b)	88	(b)	74	(b)	(b)	(b)	73	(b)	(b)	(b)	(b)	(b)	(b)	----	--	----	--	Medium
55		1650 2000 2790	82.5 100.0 139.5	90.5 87.5 88.5	60 55 ----	88 87 ----	63 57 ----	65 65 ----	62 59 ----	65 68 ----	60 65 ----	65 63 ----	60 55 ----	(b) 53 ----	(b) 50 ----	(b) 50 ----	(b) (b) ----	(b) (b) ----	---- 335 ----	-- 67 --	---- 435 ----	-- 56 --	Medium
56	Muffler 55 reversed	1650 2000	82.5 100.0	92.0 89.0	50 55	87 89	55 60	65 57	50 61	63 78	60 67	58 58	60 55	(b) 52	(b) 50	(b) 50	(b) (b)	(b) (b)	---- ----	-- --	---- ----	-- --	Medium

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.
[b] The sound-pressure level was below the range of the analyzer.

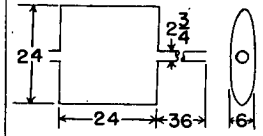
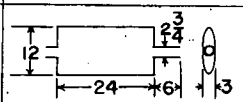
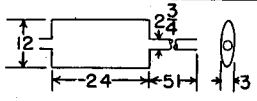
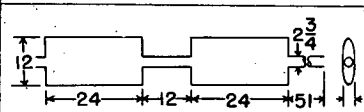
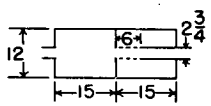
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TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Continued

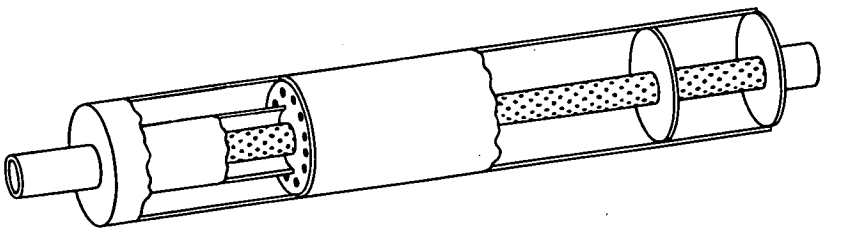
	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)															Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
57	(See fig. 2(b))	2000 2790	100.0 139.5	91.0 102.0	60 (b)	88 94	67 (b)	84 85	70 75	84 80	74 (b)	75 75	70 (b)	65 (b)	72 (b)	65 (b)	(b) (b)	(b) (b)	233 233	77 80	533 ----	76 --	------
58	(See fig. 2(c))	1650 2000 2790	82.5 100.0 139.5	85.5 90.5 96.0	60 ---- ----	77 ---- ----	55 ---- ----	65 ---- ----	56 ---- ----	70 ---- ----	(b) ---- ----	76 ---- ----	(b) ---- ----	(b) ---- ----	(b) ---- ----	(b) ---- ----	(b) ---- ----	(b) ---- ----	360 ---- ----	75 -- --	800 ---- ----	55 -- --	------
59	 (see fig. 1)	1650 2000	82.5 100.0	84.0 87.0	58 55	84 85	62 58	68 64	(b) 53	(b) 55	(b) 77	(b) 86	(b) 64	72 57	(b) 52	(b) 58	(b) 62	(b) (b)	56 ----	60 --	225 ----	60 --	Low
60		1650 2000	82.5 100.0	85.0 89.0	66 63	85 88	59 67	68 72	56 58	57 60	60 72	(b) 82	69 66	(b) 72	(b) 60	(b) 60	66 (b)	(b) (b)	700 720	66 74	820 ----	65 --	Low
61	Muffler 60 reversed	1650 2000 2790	82.5 100.0 139.5	94.0 88.0 94.5	---- 55 ----	---- 88 ----	---- 60 ----	---- 80 ----	---- 50 ----	---- 66 ----	---- 50 ----	---- 67 ----	---- 50 ----	---- 55 ----	---- (b) ----	---- (b) ----	---- (b) ----	---- (b) ----	---- ---- ----	-- -- --	---- ---- ----	-- -- --	Medium
62	 (see fig. 2(e))	1650 2000 2790	82.5 100.0 139.5	79.0 81.5 88.0	(b) (b) (b)	62 57 68	(b) (b) 50	(b) (b) 60	(b) 50 65	(b) 65 66	52 62 64	68 52 60	59 55 68	50 (b) 62	50 (b) (b)	50 (b) (b)	(b) (b) (b)	(b) (b) (b)	235 470 2100	65 60 71	117 115 330	67 55 70	Medium

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.
[b] The sound-pressure level was below the range of the analyzer.

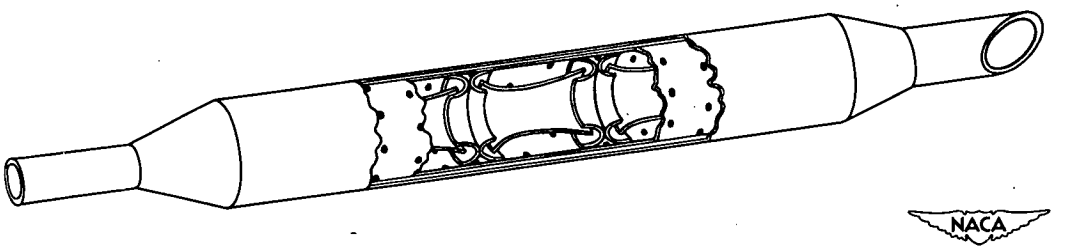
TABLE II.- RESULTS OF MUFFLER INVESTIGATION MADE WITH PROPELLER REMOVED - Concluded

	Muffler configuration (a)	Engine speed (rpm)	Fundamental firing frequency, F (cps)	Sound-pressure level (db)															Other sounds				Back pressure
				Over-all	0.5F	1.0F	1.5F	2.0F	2.5F	3.0F	3.5F	4.0F	4.5F	5.0F	5.5F	6.0F	6.5F	7.0F	cps	db	cps	db	
63	 (see fig. 2(d))	1650 2000 2790	82.5 100.0 139.5	79.0 81.5 89.0	40 (b) 50	68 58 80	50 50 55	62 53 75	51 50 65	53 65 61	68 55 66	65 50 65	58 50 78	53 51 67	57 53 71	61 57 63	55 55 (b)	58 53 (b)	619 750 110	55 50 60	115 ---- 33	55 -- 55	Medium
64		1650 2000 2790	82.5 100.0 139.5	90.0 91.6 95.7	55 (b) 63	90 91 95	61 63 70	86 74 84	63 70 67	65 65 75	65 61 73	60 61 71	55 65 73	55 60 64	55 57 65	55 (b) 63	(b) (b) (b)	(b) (b) (b)	---- 237 ----	-- 80 --	---- ---- ----	-- -- --	High
65		1650 2000 2790	82.5 100.0 139.5	85.5 87.0 93.5	45 50 57	83 80 90	61 59 68	78 81 61	62 80 65	70 76 77	58 61 79	56 67 68	60 71 68	70 62 70	66 58 65	62 55 62	60 55 (b)	55 57 (b)	225 240 240	71 83 75	660 750 ----	53 54 --	High
66	 (see fig. 2(d))	1650 2000 2790	82.5 100.0 139.5	83.5 90.0 89.5	(b) 45 55	76 79 87	63 57 69	74 75 82	56 89 67	75 77 73	60 69 85	55 66 68	57 70 71	60 68 67	65 60 67	69 60 63	55 61 (b)	52 57 (b)	618 480 245	52 72 73	660 800 48	53 58 55	High
67		1650 2000 2790	82.5 100.0 139.5	81.5 81.5 87.0	45 45 53	79 71 83	50 48 58	50 52 78	45 53 66	55 76 67	48 58 66	53 53 65	50 50 62	45 53 57	45 55 (b)	52 50 (b)	48 50 (b)	45 50 (b)	---- ---- ----	-- -- --	---- ---- ----	-- -- --	Medium
68	Mufflers 45 and 62 in series (see fig. 2(e))	1650 2000 2790	82.5 100.0 139.5	77.5 79.5 84.0	40 40 (b)	66 56 63	56 50 (b)	50 49 62	45 57 62	53 77 62	50 62 64	57 62 61	64 73 66	64 71 65	57 (b) (b)	55 (b) (b)	50 (b) (b)	50 (b) (b)	---- 490 680	-- 73 67	---- ---- 600	-- -- 66	Medium

[a] In the sketches of the configurations, all dimensions are in inches and all cross sections are circular, except where otherwise indicated.
[b] The sound-pressure level was below the range of the analyzer.

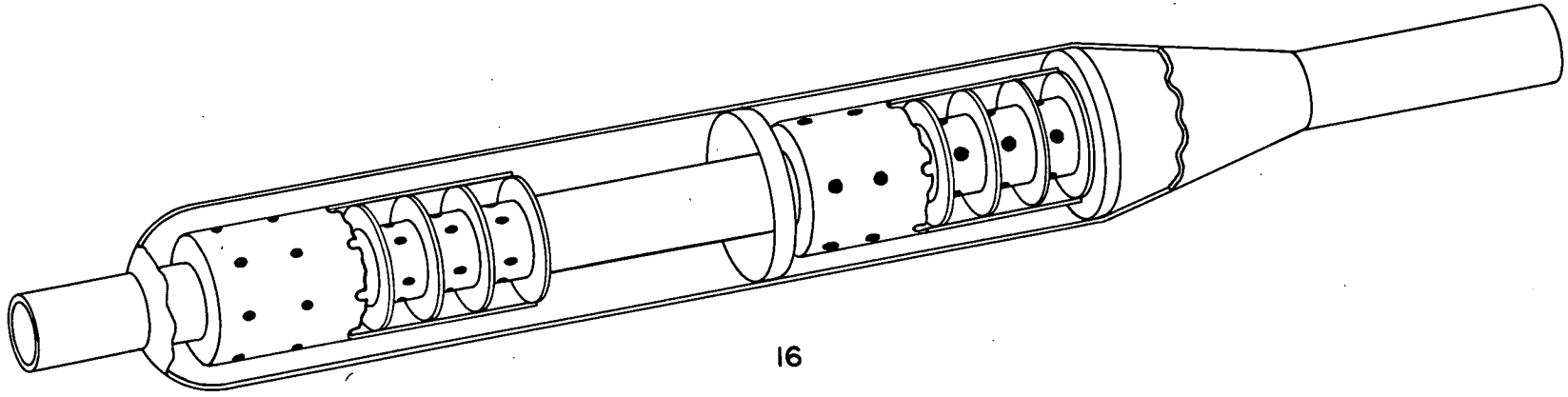


11, 12



13, 14, 15

Figure 1.– Sketches illustrating some details of typical mufflers shown in table II.



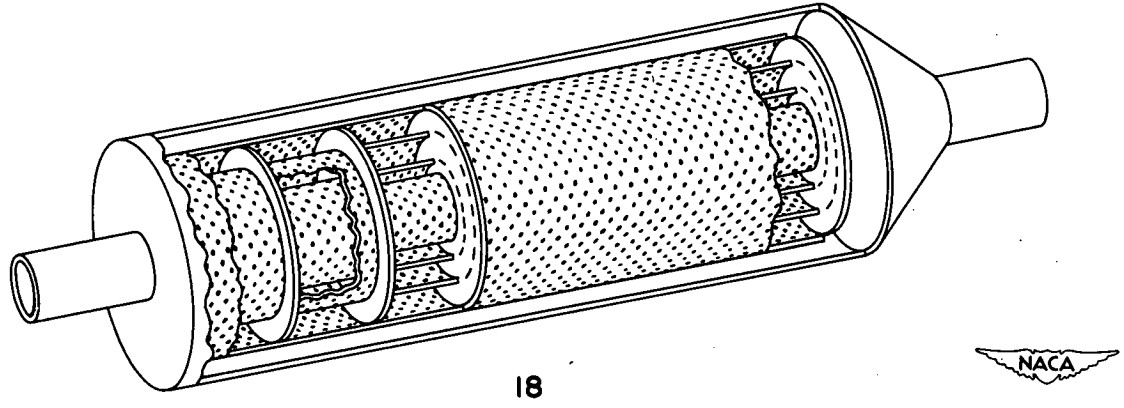


Figure 1.– Continued.

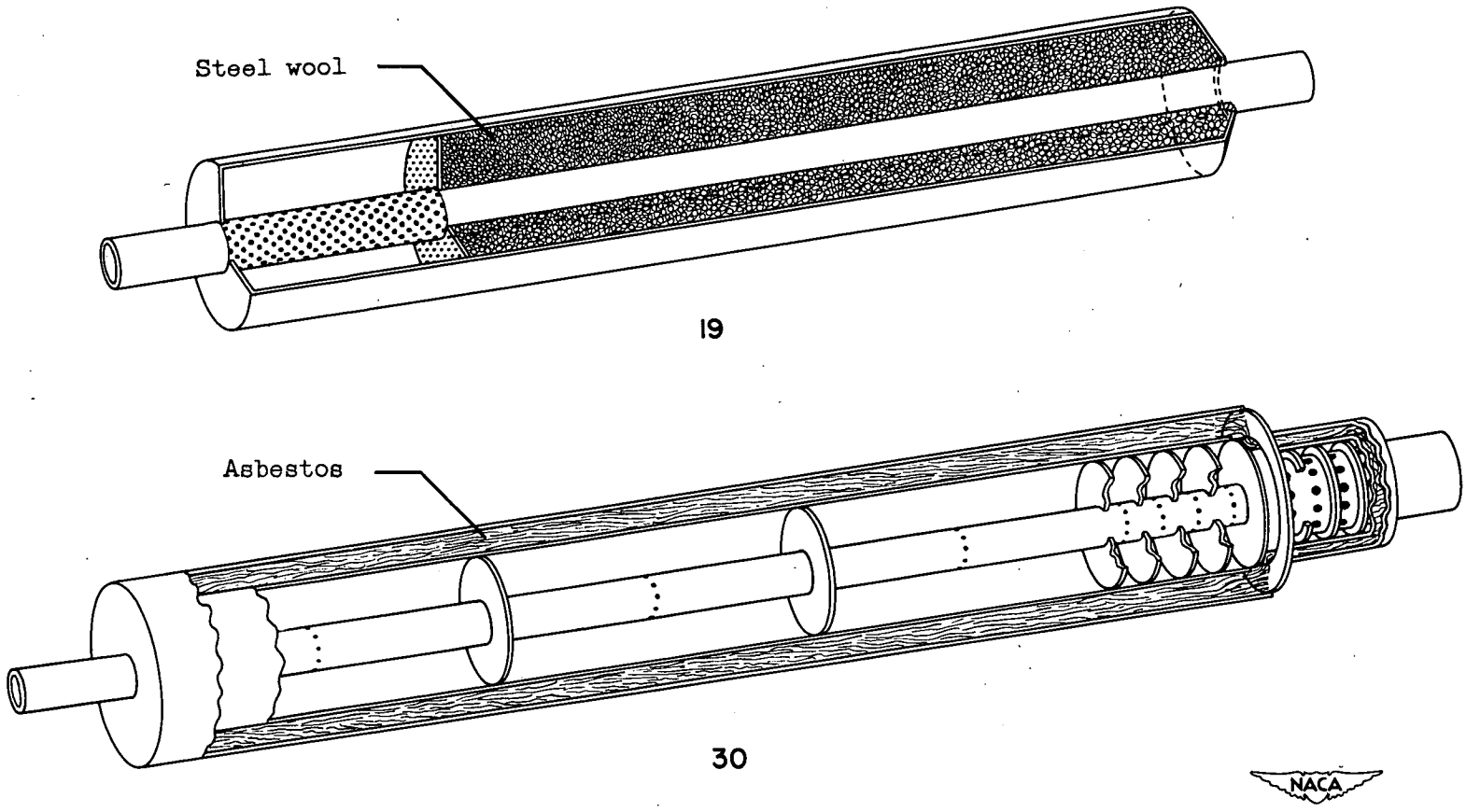
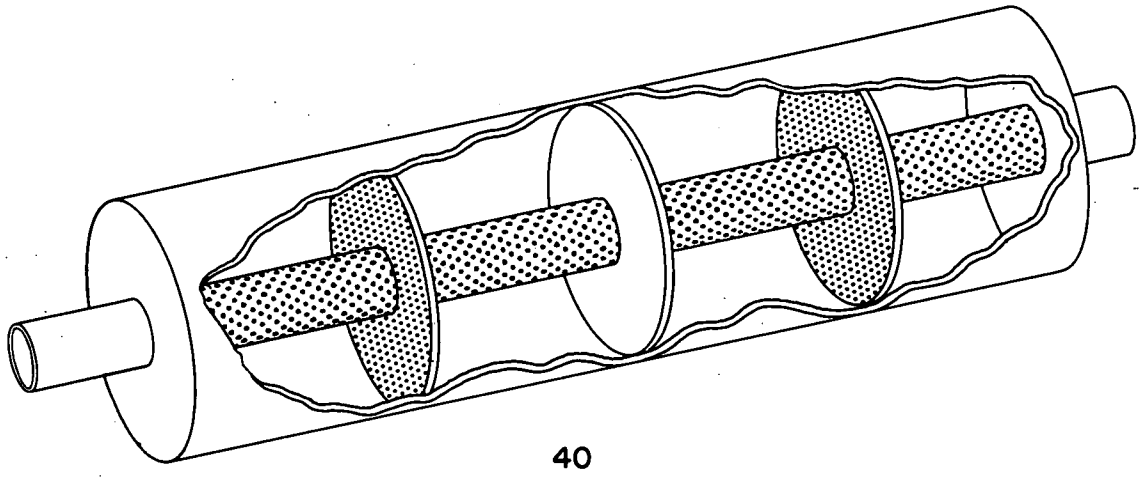


Figure 1.– Continued.



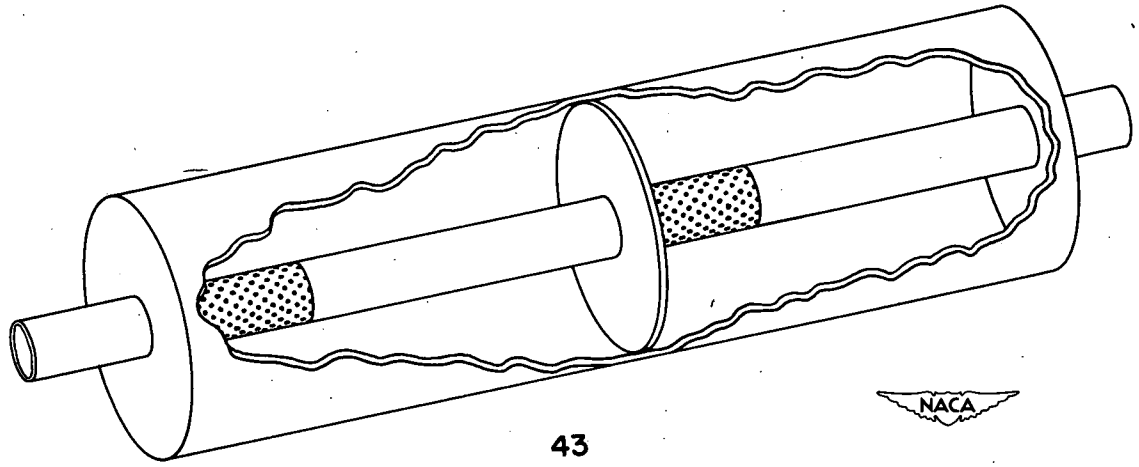
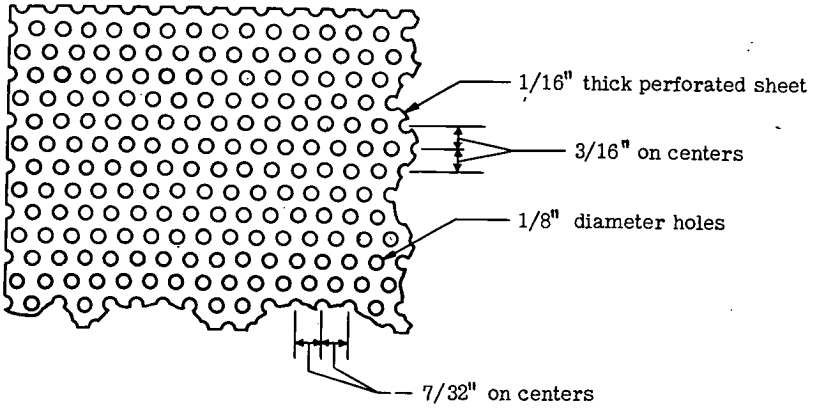
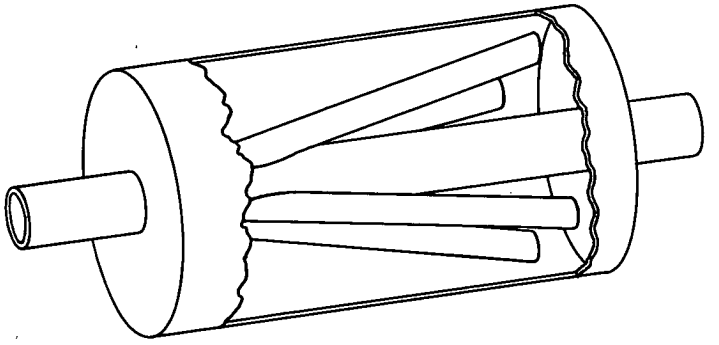


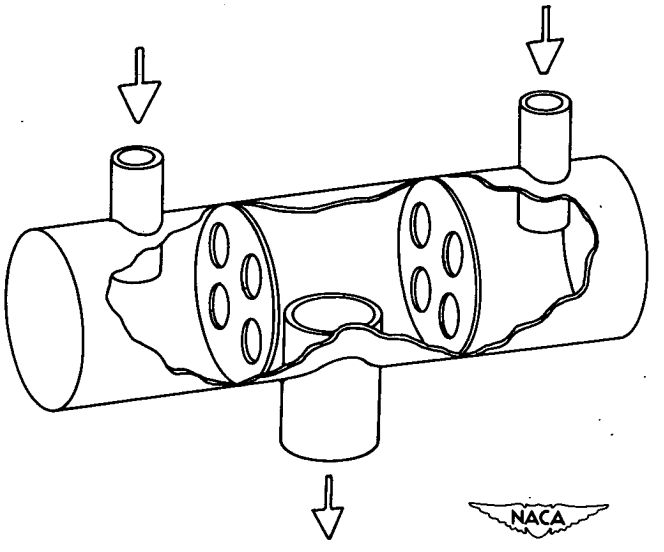
Figure 1.– Continued.



Perforated sheet steel used in mufflers 18, 19, 40, 43.



48

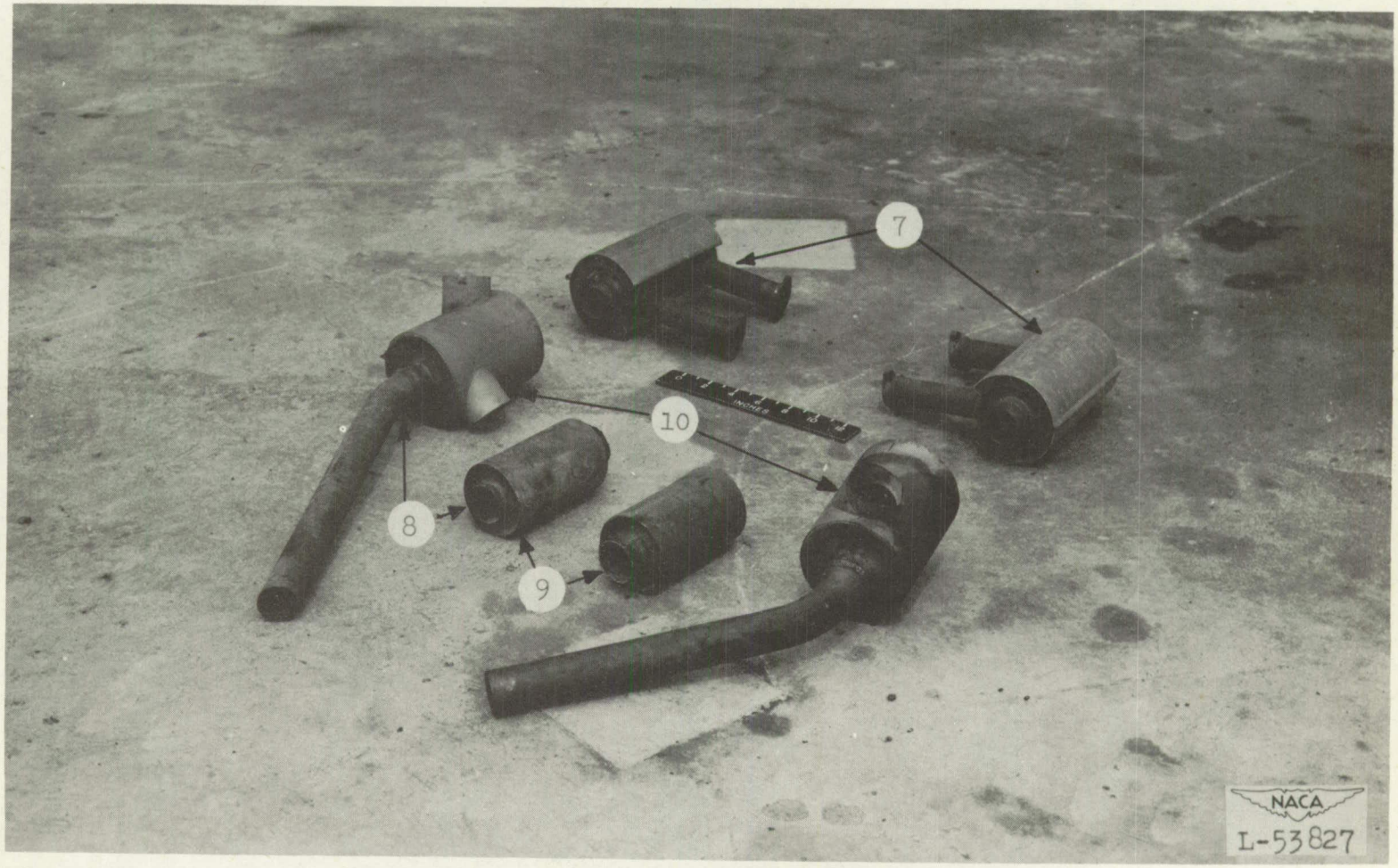


59

Figure 1.– Concluded.

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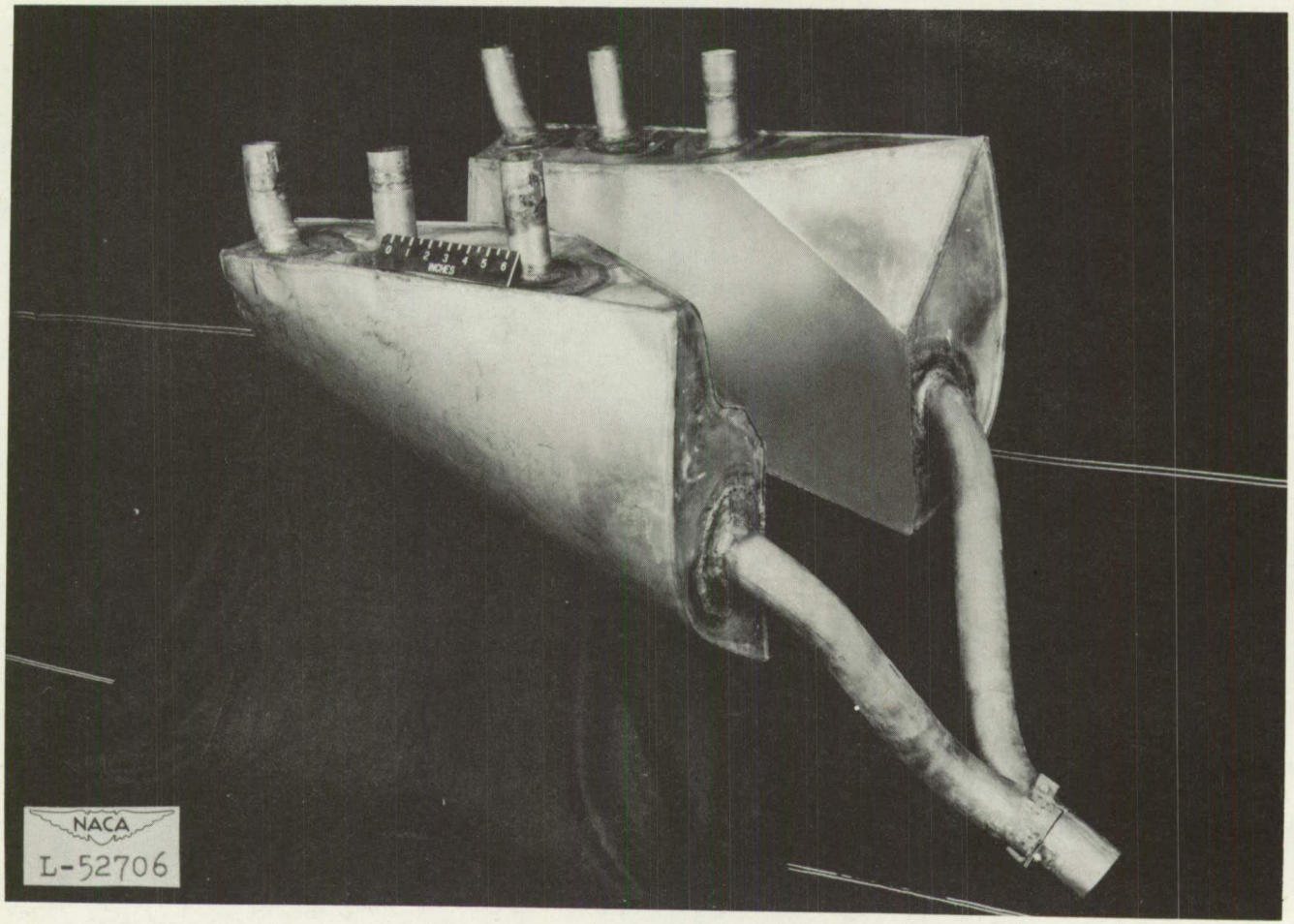


(a) Commercial aircraft mufflers and muffler-heaters.

Figure 2.- Photographs of typical mufflers shown in table II. Numbers correspond to configurations listed in table II.

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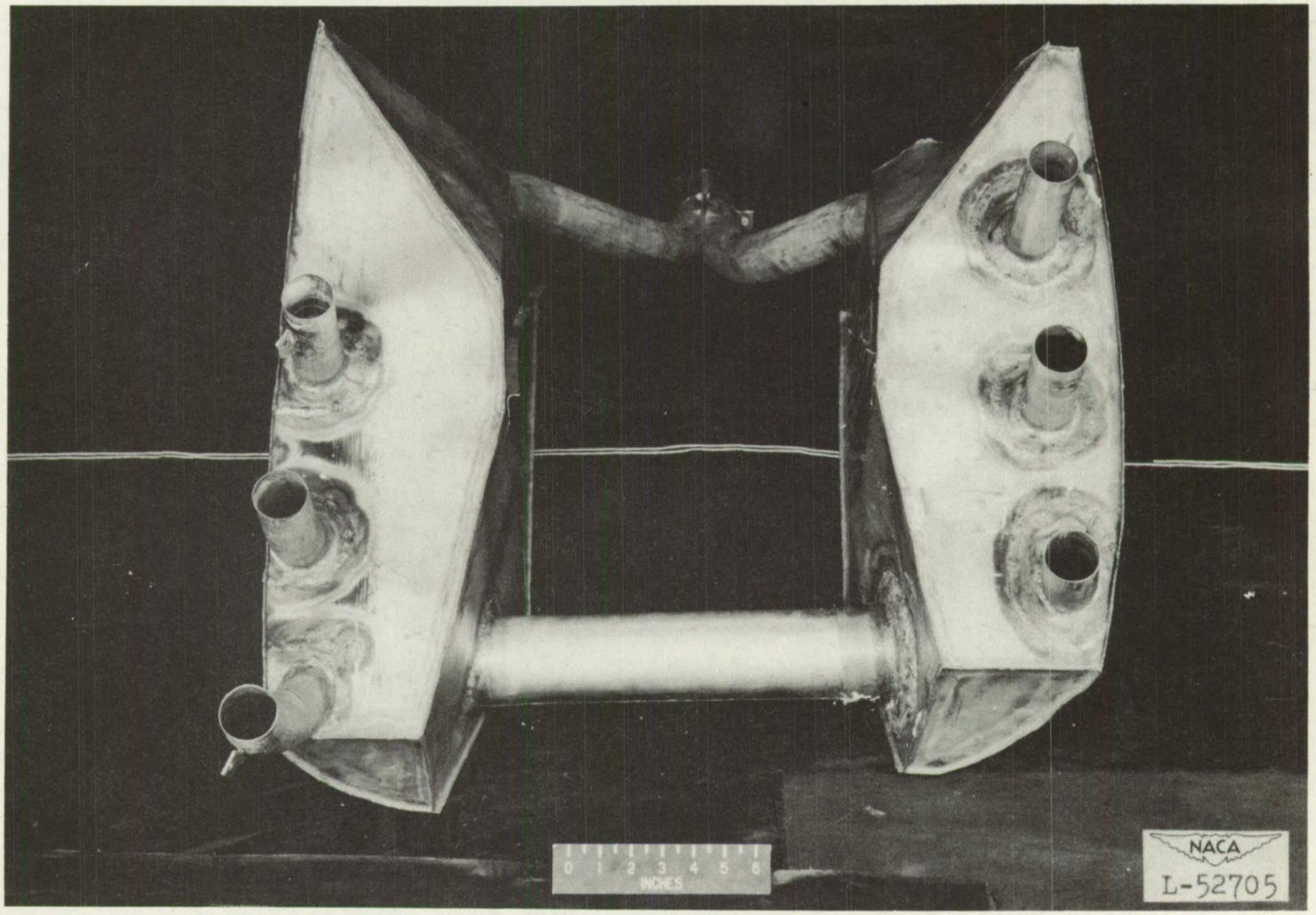


(b) Configuration 57.

Figure 2.– Continued.

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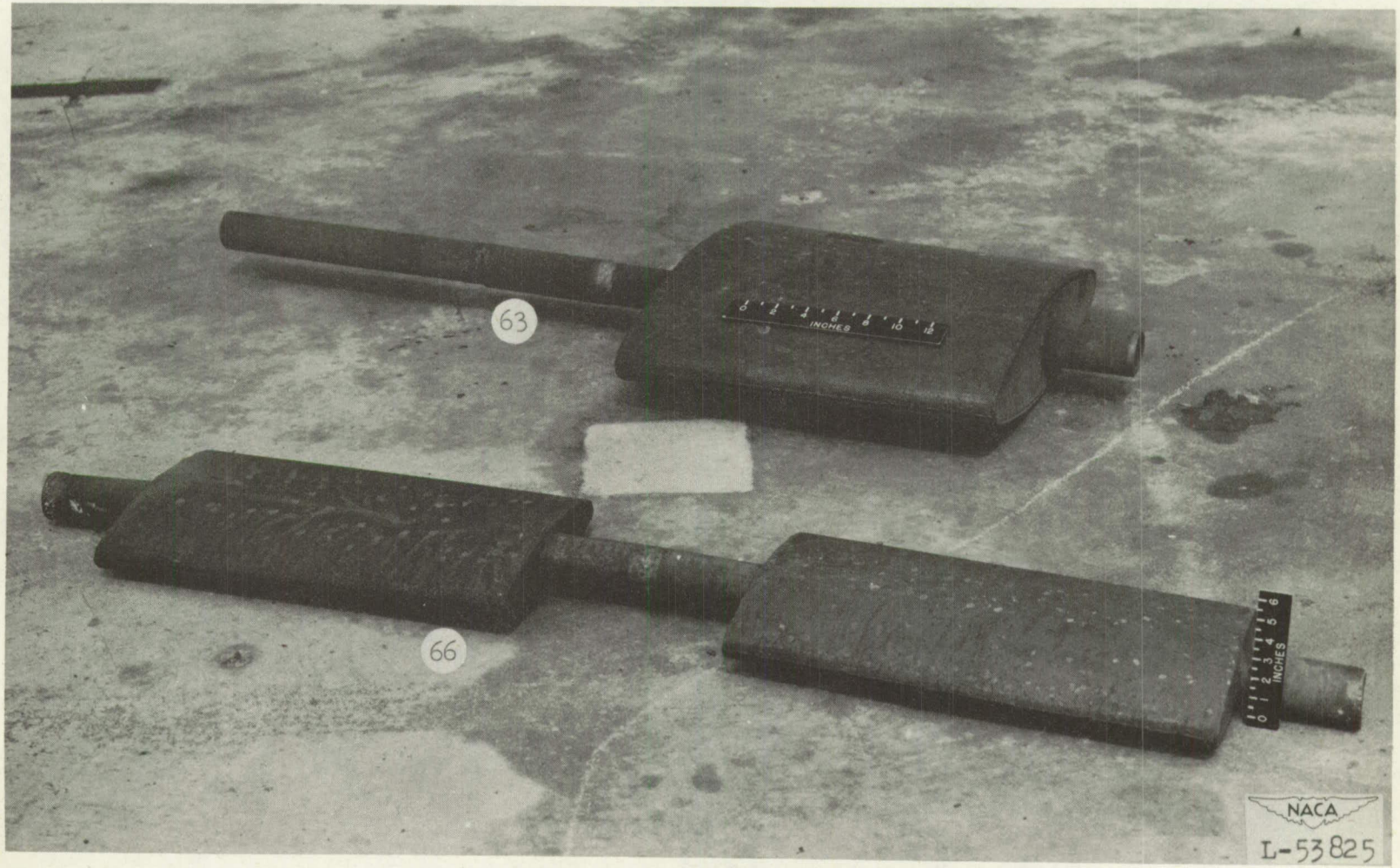


(c) Configuration 58.

Figure 2.- Continued.

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(d) Expansion-chamber mufflers with elliptical cross section.

Figure 2.- Continued.

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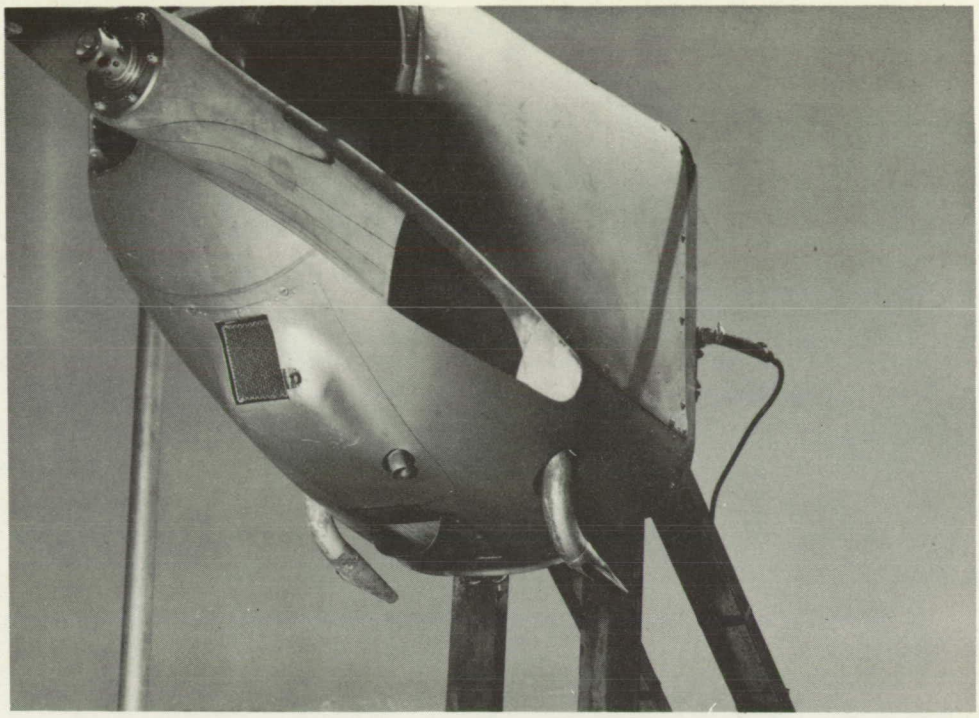


(e) Configuration 68, which consists of configurations 45 and 62 in combination.

Figure 2.- Concluded.

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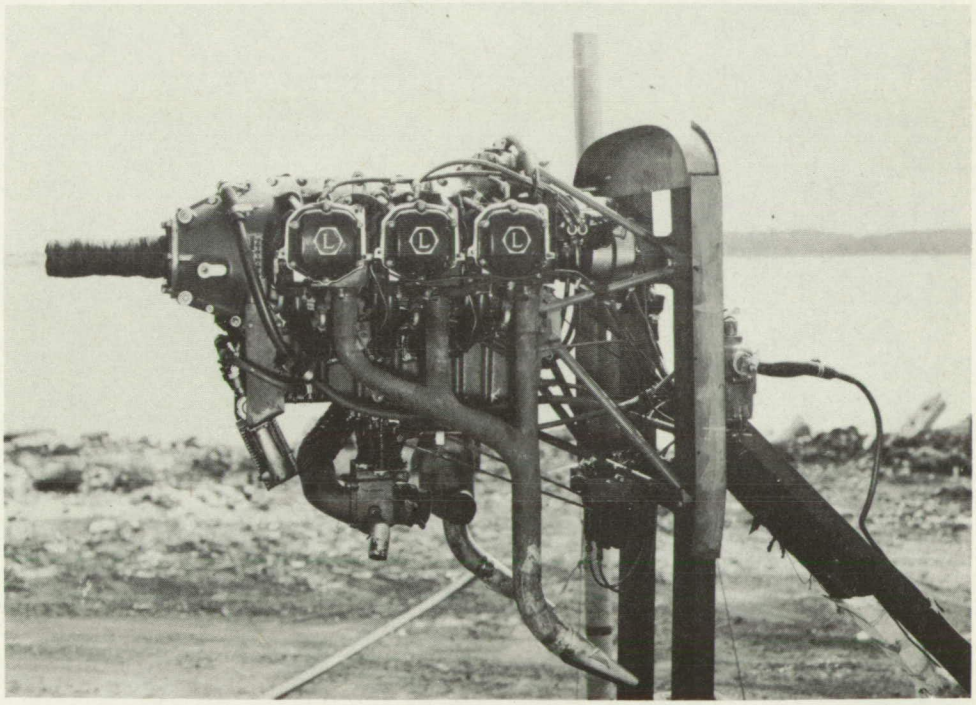


Figure 3.- Original engine-exhaust installation.

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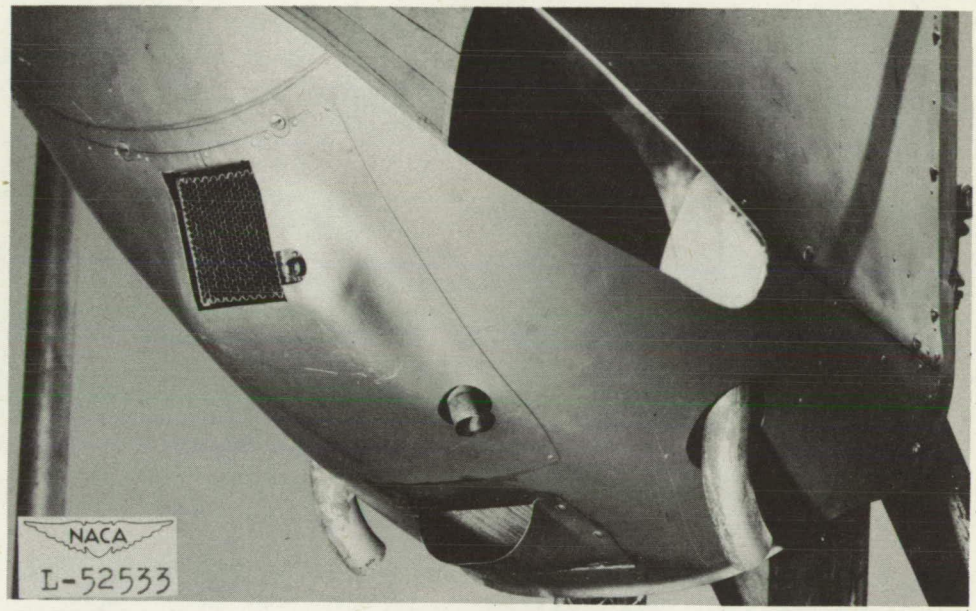


Figure 4.– Engine with exhaust exit cones removed. (Propeller was removed for configuration 2, table II.)

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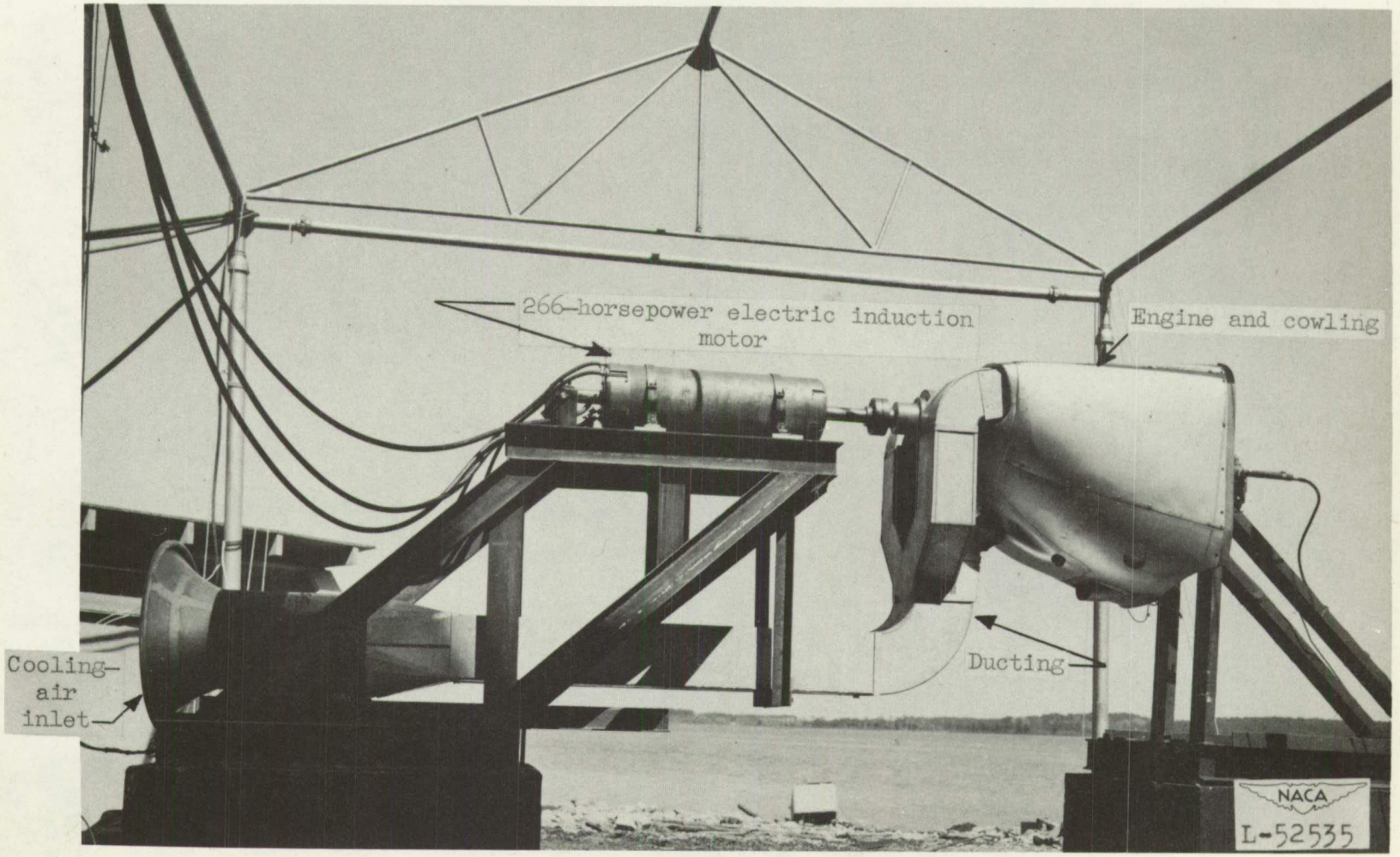


Figure 5.- Side view of dynamometer setup at the Langley full-scale tunnel.

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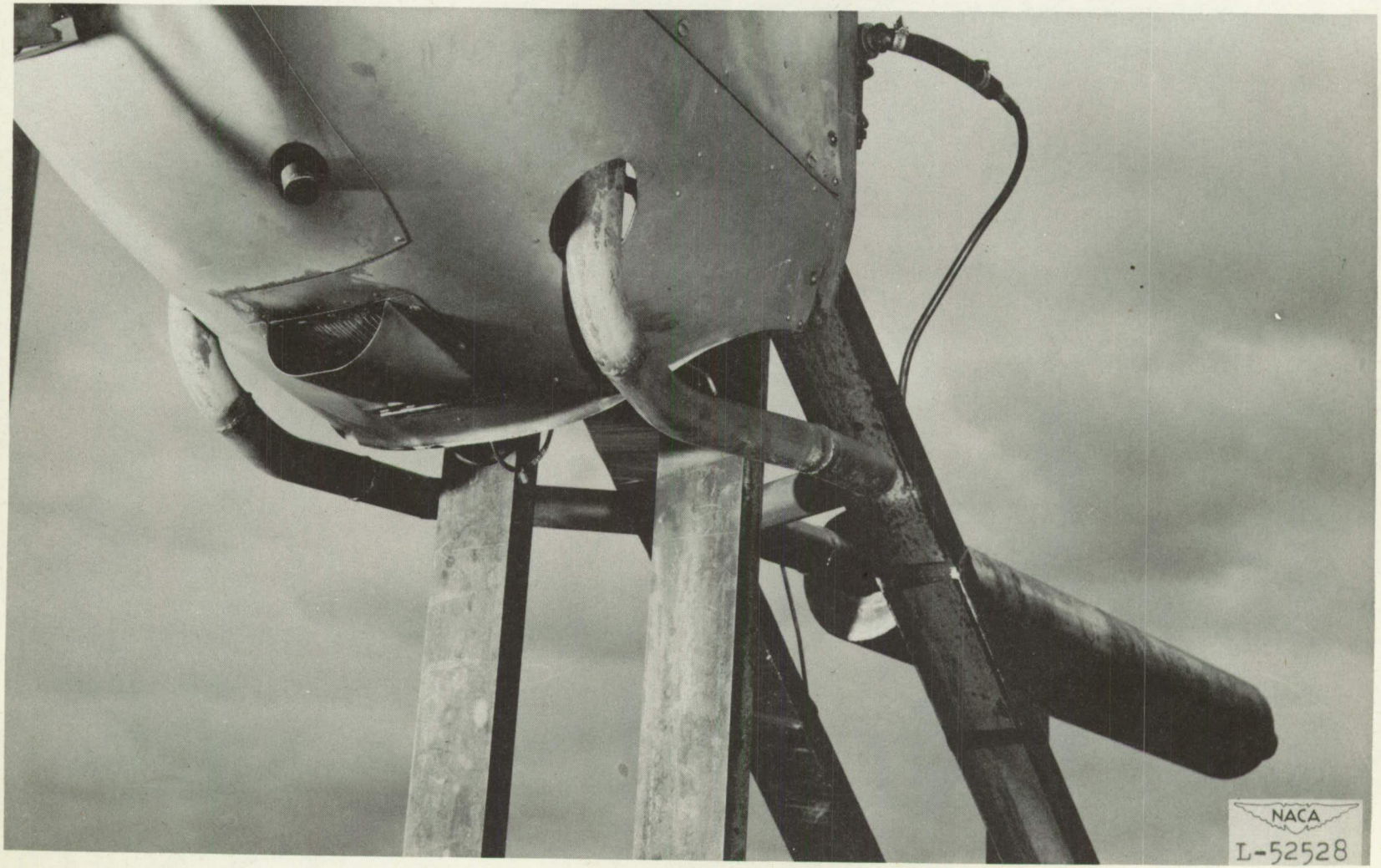


Figure 6.– View of engine with wye connecting exhausts of the two cylinder banks and emptying into a single muffler.

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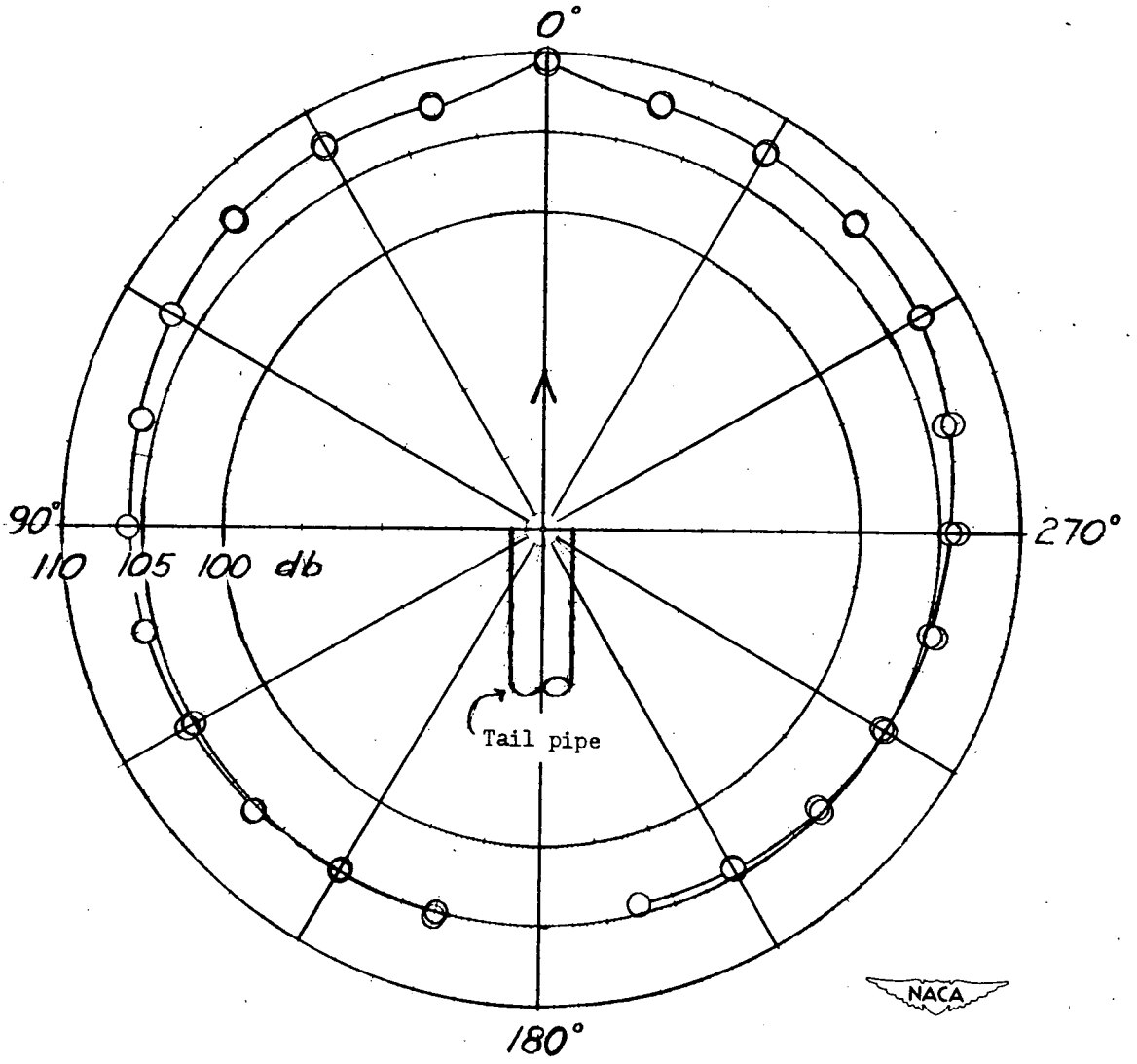


Figure 7.- Radial survey of sound field 2 feet from the end of the tail pipe. Engine speed, 1650 rpm.

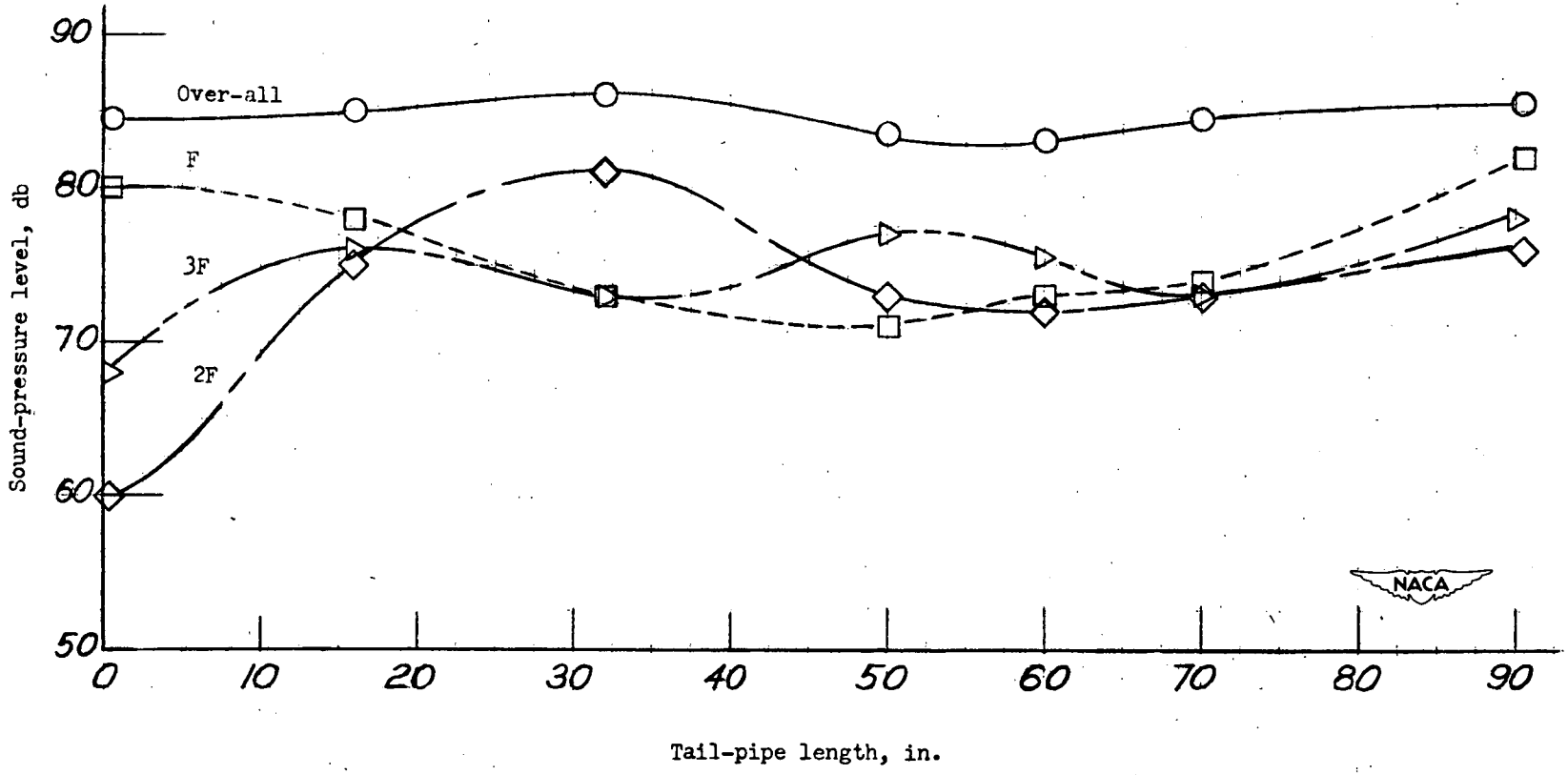


Figure 8.- Effect of tail-pipe length on sound level. Muffler configurations 22 to 28; engine speed, 2000 rpm; fundamental frequency F, 100 cps.